THE MAINTENANCE OF FERTILITY
LIMING THE LAND

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[1]In cooperation with the College of Agriculture, Ohio State University, Columbus.
[2]In cooperation with the U. S. Department of Agriculture.

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THE MAINTENANCE OF FERTILITY

LIMING THE LAND

By C. E. THORNE

In Bulletin 159 of this Station is reported the plan and earlier results of an experiment in the use of lime on crops grown in a 5-year rotation of corn, oats, wheat, clover and timothy.

There are five tracts of land in this experiment, named A, B, C, D, and E, so that each crop may be grown every season. Each tract is subdivided into 30 plots, containing one-tenth acre each, the plots being separated by paths 2 feet wide. The diagram shows the arrangement of plots and scheme of fertilizing, the fertilizers being applied to the cereal crops only; the clover and timothy, which are sown together, following without any further treatment. Every third plot, beginning with No. 1, is left continuously without fertilizer or manure. A tile drain is laid 30 inches deep under alternate paths, thus spacing the drains 36 feet apart.

The experiment is located on land which had been subjected to an exhaustive system of husbandry, the soil being a light, silty clay, overlying the shaly sandstones of the Upper Waverly.

From the beginning of the test, in 1894, there was difficulty in securing a satisfactory stand of clover, and this difficulty increased from year to year. In 1900 a dressing of one ton per acre of caustic lime was applied to the west half of Section E, as it was being prepared for corn, the lime being applied after plowing and harrowed in. The lime was applied to all the land, fertilized and unfertilized alike. This treatment was repeated on the west half of each of the succeeding sections as they came under corn until Section E was reached again, in 1905, when the liming was transferred to the east half, and continued on that half for three years. By this time it was demonstrated that the differences which were being shown in the crops were due to the liming and not to natural variations in soil, and the liming was returned to the west half, and has since been continued on that half only. Because of this shifting of the liming, sections E, B and A have had one liming on the east end, which has reduced the contrast between the two ends, so that the results which follow do not show the full effect of the treatment.

After going once over the 5 sections with quicklime, ground limestone was substituted and has been used at the rate of one ton per acre, thus carrying only about half as much calcium and magnesium as was used at first. This reduction in quantity was made because it was apparent that the full effect of the first liming had not been exhausted by the five crops of the rotation; but the later crops are indicating a need for more lime and the quantity of limestone was increased to 2 tons for the corn crop of 1914.

In 1903 the corn was so injured by white grub that no trustworthy contrast could be made between the two halves of the section (C) and in 1912 the crop was again so injured by the same pest (on Section A) that the crop was plowed under.

EFFECT OF LIME ON CORN

In Table I is given the average yield of the 12 crops of corn harvested during the period 1900-1913, the data being arranged in groups according to the principal treatments, and omitting the plots which have received only partial fertilizing, and No. 30, the plan of which was changed after several years of low fertilizing.

Table I shows that the liming has added materially to the yield of corn under every treatment and on the untreated land. The lowest gain for lime is found on the plot receiving phosphorus in basic slag, and the highest gains are on the plots receiving nitrogen in oilmeal, dried blood and sulphate of ammonia. Without lime, these carriers of nitrogen produce less total corn than does nitrate of soda, but with lime they surpass the nitrate in yield. Wherever nitrate of soda is used in the fertilizer it increases the total yield but reduces the demand for lime; the larger the applications of nitrate the greater this reduction, but no practicable application of nitrate is able to obviate the necessity for liming.

The last two columns of the table show the increase produced by the fertilizers in addition to that caused by the liming. In calculating this increase it is assumed that the variations in the yield of neighboring plots are likely to be progressive. That is, that if Plots 1 and 4, unfertilized, yield 30 and 33 bushels respectively, the probable unaided yields of Plots 2 and 3 would have been 31 and 32 bushels.

TABLE I: Average yield of CORN and increase from lime and from fertilizers for 12 years, 1900-1913,(excluding 1903 and 1912)
Bushels per acre

Treatment (Fertilizers per acre for complete rotation)	Plot No.	Yield per acre		Gain for lime	Increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus, 20 lbs. in acid phosphate	2	36.13	43.64	7.51	9.85	9.08
Phosphorus, 20 lbs.; potassium, 108 lbs. in muriate of potash	8	43.86	51.68	7.82	17.14	17.82
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	48.85	56.29	7.42	24.22	23.60
" " linseed oilmeal	21	45.89	57.56	11.67	22.13	23.06
" " dried blood	23	47.16	57.19	10.03	22.76	22.73
" " sulphate of ammonia	24	45.80	57.68	11.88	20.08	22.52
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus, 20 lbs.; and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	49.06	55.73	6.67	22.94	22.64
" " bonemeal	26	45.53	52.99	7.46	17.85	17.01
" " dissolved boneblack	27	48.60	54.77	6.17	20.29	18.68
" " basic slag	29	48.71	52.07	3.36	19.76	15.88
IV: Nitrogen, 114 lbs. in nitrate of soda, with phosphorus 20 lbs. and potassium, 108 lbs.	12	50.12	55.45	5.33	24.39	22.24
V: Yard manure, estimated to carry nitrogen 144 lbs.; phosphorus 48 lbs.; and potassium, 112 lbs.	18	56.02	62.71	6.69	31.14	28.37
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs., and potassium, 56 lbs.	20	43.10	51.93	8.83	18.65	16.68
Average unfertilized yield		25.96	34.21	8.25	.....	.....

The average yield of all the unfertilized plots is given as a comparison between the yields of different seasons, but it is never used in the calculation of increase. The increases shown in the table and those following, therefore, are those calculated from the yields of neighboring unfertilized or check plots. In the case of the unlimed land these plots have had neither lime nor fertilizer, while on the limed land the check plots have had lime but no fertilizer. In the case of the low-nitrogen treatment the fertilizers have usually produced as much increase of corn on the limed as on the unlimed land, but on the high-nitrogen plots, including the manured plots, the increase from the fertilizers is greater on the unlimed land, thus indicating that a part of the effect of liming has been the favoring of nitrification.

EFFECT OF LIME ON OATS

Table II shows the average yields of 10 crops of oats harvested in this experiment, the crops of 1902, 1903 and 1904 not having been separately harvested. The table indicates a much smaller effect on the oats crop than that found in the corn crop. It is possible that a part of this difference may be due to the fact that the corn stubble is always plowed for oats in this test, thus turning down the lime that had been applied on the surface for the corn. With the oats, as with the corn, the greatest increase from the liming is found in the low-nitrogen plots, the one to which the nitrogen is carried in sulphate of ammonia leading. On several of the high-nitrogen plots there is an actual loss of crop after liming. It will be observed that the manured plots do not receive manure on the oats crop, that crop following as a gleaner after corn.

EFFECT OF LIME ON WHEAT

Table III shows that the wheat crop is responding regularly to the liming, the only treatment which fails to show a larger yield on the limed than on the unlimed land being the one in which the phosphorus is carried in basic slag. The largest increase from lime is found on the plot receiving its nitrogen in sulphate of ammonia. Without lime this plot falls 2½ bushels below the one dressed with nitrate of soda, but with lime the two carriers of nitrogen give exactly the same yield. On the no-nitrogen and low-nitrogen plots, excepting No. 21, the increase from fertilizers is greater on the limed than on the unlimed land.

EFFECT OF LIME ON CLOVER

The oat-stubble is plowed for wheat, thus bringing the lime near the surface again, besides mixing it very thoroughly through the soil, and the clover responds to the liming with a larger rate of

TABLE II: Average yield of OATS and increase from lime and from fertilizers for the 10 years, 1901, and 1905 to 1913 inclusive.
Bushels per acre

Treatment (Fertilizers per acre for complete rotation)	Plot No.	Yield per acre		Gain or loss (—) for lime	Increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus, 20 lbs. in acid phosphate	2	39.20	42.07	2.87	10.74	11.00
Phosphorus, 20 lbs., potassium, 108 lbs. in muriate of potash	8	42.57	46.07	3.50	15.75	16.27
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	51.18	50.55	—.63	23.55	21.19
" " linseed oilmeal	21	47.09	49.86	2.77	20.16	19.79
" " dried blood	23	47.61	48.47	.	20.86	18.41
" " sulphate of ammonia	24	46.23	50.04	3.81	19.19	19.50
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus, 20 lbs., and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	49.61	47.61	—2.00	22.35	18.06
" " bonemeal	26	45.06	45.20	.14	16.99	14.23
" " dissolved boneblack	27	47.59	46.40	—1.19	18.77	15.50
" " basic slag	29	45.66	44.54	—1.12	16.10	13.70
IV: Nitrogen, 114 lbs. in nitrate of soda with phosphorus 20 lbs, and potassium, 108 lbs.	12	47.87	48.80	.93	20.60	19.00
V: Yard manure, estimated to carry nitrogen 144 lbs., phosphorus 48 lbs., and potassium, 112 lbs.	18	42.08	43.48	1.40	14.32	13.27
Yard manure, estimated to carry nitrogen 72 lbs. phosphorus, 24 lbs., and potassium, 56 lbs.	20	36.04	39.72	3.68	8.63	9.15
Average unfertilized yield		27.51	30.23	2.72	....	.....

increase than is given by any other crop. Not only does the clover show a great direct increase from the liming, but in every instance, excepting only the plot to which phosphorus is carried in basic slag, the residual increase from the fertilizers which have been applied to the previous crops is materially greater on the limed than on the unlimed land.

The effect of nitrate of soda is strikingly brought out in the comparison of Plots 17, 21, 23 and 24, and of this group of plots with those receiving the larger quantity of nitrate. On the unlimed land the increase from the complete fertilizers used on Plots 21, 23 and 24 is no greater in the average than on Plot 8, which receives no nitrogen, while that on Plot 17 is materially greater. The behavior of the clover crop is very different from that of the cereal crops, for although in these crops also nitrate of soda has been more effective than the other carriers of nitrogen, the difference has been less conspicuous than with the clover, notwithstanding the fact that nitrate of soda is supposed to be relatively more evanescent in its effect, as compared with nitrogen in organic materials. Considering all the evidence the conclusion seems to be warranted that a part of the superior effect of nitrate of soda on this acid soil has been due to the sodium contained, that element having been liberated when the salt was being decomposed to give up its nitrogen to the crops which preceded the clover.

That the increase in the quantity of nitrate of soda, as used on Plot 12, has not produced a greater effect, may be explained on the assumption that the formula used on this plot has not carried enough phosphorus or potassium, one or both, to properly balance the nitrogen given, and hence a considerable part of the nitrate has been wasted.

On the third group of plots the proportion of clover in the stand has been conspicuously greater on the unlimed land to which the phosphorus is carried in bonemeal or basic slag than under other treatments, and this has been especially the case on the manured land. The manured plots have also grown more timothy and fewer weeds during the season immediately after seeding than the fertilized land. The gain for lime, moreover, has been relatively smaller on the manured than on fertilized land. These points are explained by the absence of sulphuric acid in the manure and the bonemeal and basic slag mixture, and by the considerable amount of lime carried in the manure.

But neither nitrate of soda nor bonemeal nor basic slag nor any practicable combination of these materials, will furnish sufficient alkali to neutralize this acid soil, unless used in such quantity that the cost will be prohibitive.

TABLE III: Average yield of WHEAT and increase from lime and from fertilizers for the 8 years, 1906-1913.
Bushels per acre.

Treatment (Fertilizers per acre for complete rotation)	Plot No.	Yield per acre		Gain or loss (—) for lime	Increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus, 20 lbs. in acid phosphate	2	20.90	24.19	3.29	7.47	8.54
Phosphorus 20 lbs., potassium, 108 lbs. in muriate of potash	8	21.67	24.29	2.62	8.08	9.05
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	25.89	28.80	2.91	13.88	14.61
" " linseed oilmeal	21	24.81	26.75	1.94	12.88	11.73
" " dried blood	23	23.07	26.92	3.85	11.26	12.06
" " sulphate of ammonia	24	23.38	28.80	5.42	11.35	13.90
III: Nitrogen, 76 lbs., in nitrate of soda, with phosphorus, 20 lbs., and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	30.70	30.82	.12	17.44	15.71
" " bonemeal	26	26.18	27.23	1.05	14.06	12.40
" " dissolved boneblack	27	26.61	28.68	2.07	14.64	13.96
" " basic slag	29	27.87	26.46	—1.41	16.04	11.85
IV: Nitrogen, 114 lbs, in nitrate of sod with phosphorus, 20 lbs. and potassium, 108 lbs.	12	29.60	32.89	3.29	16.73	17.65
V: Yard manure, estimated to carry nitrogen 114 lbs., phosphorus 48 lbs., and potassium, 112 lbs.	18	28.40	31.42	3.02	16.09	16.60
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs., and potassium, 56 lbs.	20	23.23	26.02	2.79	10.96	10.79
Average unfertilized yield		12.64	15.01	2.37	.....	.....

TABLE IV: Average yield of CLOVER HAY and increase from lime and from fertilizers for 11 years, 1903-1913
Pounds per acre

Treatment (Fertilizers per acre for complete rotation, all applied for corn, oats and wheat)	Plot No.	Yield per acre		Gain for lime	Increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus, 20 lbs. in acid phosphate	2	1,554	2,250	696	461	700
Phosphorus, 20 lbs., potassium, 108 lbs. in muriate of potash	8	2,286	3,476	1,190	883	1,439
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	2,596	3,842	1,246	1.287	1,968
" " linseed oilmeal	21	2 256	3,409	1,153	963	1,589
" " dried blood	23	2,123	3,515	1,392	793	1,708
" " sulphate of ammonia	24	2,256	3,736	1,480	859	1,842
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus 20 lbs., and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	2,796	3,631	835	1,438	1,718
" " bonemeal	26	3,135	3,981	846	1,654	1,978
" " dissolved boneblack	27	2,636	3,524	888	1,137	1,497
" " basic slag	29	3,072	3,579	507	1,554	1,530
IV: Nitrogen, 114 lbs. in nitrate of soda, with phosphorus 20 lbs. and potassium, 108 lbs.	12	2,853	3,765	912	1,481	1,845
V: Yard manure, estimated to carry nitrogen 144 lbs., phosphorus 48 lbs. and potassium, 112 lbs.	18	3,582	4,708	1,126	2 253	2,761
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs. and potassium, 56 lbs.	20	2,517	3,312	795	1,195	1,392
Average unfertilized yield		1,409	1,983	574	.	.....

TABLE V: Average yield of TIMOTHY HAY and increase from lime and from fertilizers for 7 years, 1906 to 1913 (excluding 1909)
Pounds per acre

Treatment (Fertilizers per acre for complete rotation, all applied on corn, oats and wheat)	Plot No.	Yield per acre		Gain for lime	Increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus 20 lbs. in acid phosphate	2	2,992	3,934	942	292	803
Phosphorus, 20 lbs., potassium, 108 lbs. in muriate of potash	8	2,982	4,008	1,026	546	819
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	3,197	4,635	1,438	839	1,456
" " linseed oilmeal	21	3,068	4,416	1,348	717	1,234
" " dried blood	23	2,987	4,388	1,401	548	1,185
" " sulphate of ammonia	24	2,923	4,617	1,694	365	1,261
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus, 20 lbs, and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	3,507	4,389	882	1,081	1,273
" " bonemeal	26	3,436	4,876	1,442	744	1,352
" " dissolved boneblack	27	3,184	4,607	1,423	480	1,068
" " basic slag	29	3,837	4,567	730	1,120	1,014
IV: Nitrogen, 114 lbs., in nitrate of soda, with phosphorus 20 lbs. and potassium, 108 lbs.	12	3,517	4,434	917	1,078	1,391
V: Yard manure, estimated to carry nitrogen 144 lbs., phosphorus, 48 lbs, and potassium, 112 lbs.	18	4,470	5,742	1,272	2,083	2,430
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs., and potassium, 56 lbs	20	3,627	4,841	1,214	1,244	1,527
Average unfertilized yield		2,512	3,225	713	.....	.....

EFFECT OF LIME ON TIMOTHY

The results on the timothy crop are given in Table V. On the unlimed land the timothy crop shows the same neglect of organic and ammonia nitrogen on Plots 21, 23 and 24, as compared with Plot 8, as that shown by the clover, but shows a somewhat greater response than clover to these carriers of nitrogen after lime has been added. The increase of nitrogen in nitrate of soda, in Group III, accompanied as it has been by a reduction of phosphorus, has not produced a further increase in yield on the limed land.

The total gain for lime in the timothy crop has been greater, and the percentage gain nearly as great as in the clover, and in both it has been much greater than in the oats or wheat, notwithstanding the fact that these crops have been grown at an earlier period after the liming than the clover and timothy.

THE FINANCIAL OUTCOME

Table VI gives the total value of all the crops for each rotation for the limed and unlimed land, the value of the gain for lime and that of the increase from the fertilizers, rating corn at 40 cents per bushel, oats at 30 cents and wheat at 80 cents, with stover at $3.00 per ton, straw at $2.00 and hay at $8.00.

As shown by this table, on the unlimed land the total value of the 5 crops of the rotation has amounted to $49.40 for the average of the unfertilized land and to $67.80 for the land receiving acid phosphate only, but the value of the increase on this land over the neighboring unfertilized land has been $17.81, because of the fact that the increase is calculated, not on the average of all the unfertilized plots, but on those nearest the treatment under consideration.

When the land has had lime in addition to the phosphate, the yield has run to $81.80 in value, or $14.00 more than that of the unlimed land, while the increase from the fertilizer has amounted to $21.52, making a total gain for lime and fertilizer of $35.52.

The addition of muriate of potash to the fertilizer has increased the total value of the crops to $76.28 on the unlimed and to $92.33 on the limed land, the gain for the fertilizer being $26.38 on the unlimed, and $30.95 on the limed land; the gain for lime alone being $16.05 and that for lime and fertilizer amounting to $47.00

When nitrogen in sulphate of ammonia has been added to this combination of phosphorus and potassium, the phosphorus being increased by 50 percent, the value of the produce has been $80.04 on the unlimed land and $104.15 on the limed land. Comparing with the neighboring unfertilized land, we find that this combination has increased the yield by $31.15 on the unlimed, and by

TABLE VI: Average value of crops for one rotation and value of increase for lime and for fertilizers.*

Treatment (Fertilizers per acre for each rotation)	Plot No.	Value per acre of total crops		Value of gain for lime	Value of increase from fertilizers	
		Unlimed	Limed		Unlimed	Limed
I: Without nitrogen:						
Phosphorus, 20 lbs., in acid phosphate	2	$67.80	$81.80	$14.00	$17.80	$21.52
Phosphorus 20 lbs., potassium, 108 lbs. in muriate of potash	8	76.28	92.33	16.05	26.38	30.95
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.						
Nitrogen in nitrate of soda	17	87.76	104.49	16.73	40.96	45.47
" " linseed oilmeal	21	82.20	99.82	17.62	35.61	39.04
" " dried blood	23	80.40	99.71	19.31	33.18	39.04
" " sulphate of ammonia	24	80.04	104.15	24.10	31.15	42.02
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus, 20 lbs., and potassium, 108 lbs.						
Phosphorus in acid phosphate	11	93.83	103.16	9.33	44.52	43.16
" " bonemeal	26	87.60	100.90	13.30	36.52	37.31
" " dissolved boneblack	27	87.28	100.81	13.53	35.70	37.24
" " basic slag	29	92.36	96.59	4.23	40.25	32.05
IV: Nitrogen, 114 lbs. in nitrate of soda, with phosphorus 20 lbs. and potassium, 108 lbs.	12	92.87	106.13	13.26	43.95	46.17
V: Yard manure, estimated to carry nitrogen 144 lbs., phosphorus 48 lbs., and potassium, 112 lbs.	18	99.08	115.05	15.97	51.09	53.56
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs., and potassium, 56 lbs.	20	78.58	94.49	15.91	30.96	32.12
Average unfertilized yield		49.40	61.40	12.00	.....	.....

*Valuations: Corn, 40 cents per bu.; oats, 30 cents; wheat, 80 cents; hay, $8.00 per ton; stover $3.00 and straw $2.00.

$42.02 on the limed land. In other words, the fertilizers alone have increased the yield by $31.15 and the fertilizers and lime have increased it by $66.12.

When nitrate of soda has been substituted for sulphate of ammonia as the carrier of nitrogen the increase from the fertilizers has been nearly $10.00 greater on the unlimed land, and $3.45 greater on the limed land than that produced by the combination carrying its nitrogen in sulphate of ammonia.

The combined increase from lime and fertilizers carrying nitrate of soda has averaged $62.19, and that from lime and fertilizers carryng sulphate of ammonia has averaged $66.12; the total yields, however, have had the same value, within a few cents, indicating that the higher increase found after sulphate of ammonia in this case has been due to a lower rate of yield of the unfertilized land.

Where the nitrogen has been given in organic form, in linseed oilmeal or dried blood, the increase on the unlimed land has been a little greater than that from sulphate of ammonia, but on the limed land the sulphate of ammonia has produced the greater increase.

In the case of carriers of phosphorus, basic slag seems to have been a little less effective than acid phosphate on unlimed land, while on the limed land acid phosphate has produced a decidedly greater effect than the slag, the difference amounting to ten dollars for each rotation. In comparing these phosphates the total phosphorus in basic slag has been set against the available phosphorus in acid phosphate. Even on this basis the cost of a pound of phosphorus is usually a little greater in basic slag than in acid phosphate.

The value of increase from fertilizers is $3.66 greater on the unlimed half of Plot 11, receiving for each rotation 480 pounds of nitrate of soda and 320 pounds of acid phosphate, than on Plot 17, receiving 240 pounds of nitrate of soda and 480 pounds of acid phosphate, but the fertilizers for Plot 11 have cost $5.90 more than for Plot 17. On the limed half the increase on plot 17 is greater than on Plot 11. The still larger application of nitrate of soda, on Plot 12, fails to meet a corresponding response in increase of crop. Evidently, so far as this soil and these crops are concerned, the ratio of nitrogen to phosphorus has been more effective on Plot 17 than on either Plot 11 or Plot 12.

In Table VII is shown the cost of treatment and the net gain per acre for the limed and unlimed land for each rotation, the cost of liming being estimated at five dollars per acre, and the nitrogen and phosphorus in other carriers being computed at the same cost as in nitrate of soda and acid phosphate, except in the case of manure,

TABLE VII: Cost of treatment and net gain per acre

Treatment	Plot No.	Cost of treatment*		Net gain per acre	
		Unlimed	Limed	Unlimed	Limed
I: Without nitrogen:					
Phosphorus, 20 lbs. in acid phosphate	2	$ 2.60	$ 7.60	$15.20	$24.20
Phosphorus, 20 lbs., potassium, 108 lbs. in muriate of potash	8	9.10	14.10	17.28	28.33
II: Nitrogen, 38 lbs., with phosphorus, 30 lbs., and potassium, 108 lbs.					
Nitrogen in nitrate of soda	17	17.60	22.60	23.46	35.09
" " linseed oilmeal	21	17.60	22.60	18.01	30.63
" " dried blood	23	17.60	22.60	15.58	29.89
" " sulphate of ammonia	24	17.60	22.60	13.55	32.65
III: Nitrogen, 76 lbs. in nitrate of soda, with phosphorus, 20 lbs., and potassium, 108 lbs.					
Phosphorus in acid phosphate	11	23.50	28.50	21.02	25.35
" " bonemeal	26	23.50	28.50	13.02	21.32
" " dissolved boneblack	27	23.50	28.50	12.20	20.73
" " basic slag	29	23.50	28.50	16.75	15.98
IV: Nitrogen, 114 lbs. in nitrate of soda, with phosphorus 20 lbs. and potassium, 108 lbs.	12	30.70	35.70	13.25	21.51
V: Yard manure, estimated to carry nitrogen 144 lbs., phosphorus 48 lbs., and potassium, 112 lbs	18	32.00	37.00	19.09	35.06
Yard manure, estimated to carry nitrogen 72 lbs., phosphorus, 24 lbs., and potassium, 56 lbs.	20	16.00	21.00	14.96	25.87

*Valuations: In fertilizers, phosphorus, 13 cents per lb.; potassium, 6 cents; nitrogen, 19 cents. In manure, nitrogen is computed at 15 cents and phosphorus at 7½ cents—the approximate cost of these elements in tankage and fine bone as estimated in the Official Report on Commercial Fertilizers for 1913, of the Agricultural Commission of Ohio.

where the nitrogen is estimated at 15 cents and the phosphorus at 7½ cents per pound, following the valuation for these elements in tankage and fine bone in the Official Report on Commercial Fertilizers for 1913 of the Agricultural Commission of Ohio. At these valuations a ton of yard manure would be worth two dollars, and the outcome shows that, when supplemented by liming, the yard manure has produced a very profitable increase, although the gain per pound of fertilizing elements contained is not equal to that from the best proportioned chemical application. Other experiments* have shown that before we can expect to realize the full effect of manure we must re-enforce it with some carrier of phosphorus, and must avoid the wastes which occur in the ordinary barnyard.

CONCLUSIONS

The experiments reported in this bulletin show that on soils deficient in lime it is as necessary to make good this deficiency as it may be to make good that of nitrogen, phosphorus or potassium. They show, moreover, that lime does not take the place of other fertilizing elements, but only accomplishes its full effect when used in connection with liberal manuring or fertilizing.

WHAT IS LIME?†

Everyone who has handled a lump of quicklime has noticed that it is much lighter in weight than an unburnt limestone of equal bulk. This means that one of the materials of which the original stone was composed has been driven off from the stone by the burning, and has escaped as an invisible gas into the atmosphere. This gas is carbon di-oxide (di meaning two) the "carbonic acid gas" of the older chemistry. It is the same gas which is breathed out of the lungs, and if we pass our breath through a tube into the bottom of a tumbler of limewater a white cloud will be formed by the union of the carbon di-oxide of the breath with the lime dissolved in the water, thus reversing the results attained by burning; for the white cloud in the tumbler and the limestone in the quarry are both the same substance, namely; carbonate of lime.

If we first thoroughly dry a pure limestone and then burn it, we shall find that it has lost about 44 percent of its original dry weight. That is, 100 pounds of pure, dry limestone, or carbonate of lime, will produce about 56 pounds of lime. But what is lime?

*See Bulletin 183 of this Station.

†From the Official Report for 1913 on Commercial Fertilizers and Agricultural Lime of the Agricultural Commission of Ohio.

CALCIUM

The chemist is able to separate the burnt lime into two constituents, one of which again is the oxygen gas which constitutes about one-fifth of the air we breathe, while the other is a brilliant, light yellow metal called calcium, which rapidly tarnishes when exposed to moist air by recombining with oxygen and returning to lime. This elementary metal, calcium, is the essential constituent to which lime owes its peculiar properties. Oxygen and carbonic acid may be found in thousands of other combinations which have none of the characteristics of lime and perform none of its functions. We use lime, therefore, simply as a convenient carrier of calcium.

HYDRATED LIME

If we expose a lump of freshly burnt lime to ordinary moist air, in the course of a few days, or weeks, depending largely upon the amount of moisture in the air, it will be found to have crumbled into a fine powder. In other words, it is air slaked. We may accomplish this result much more quickly by pouring water on the lump of lime, when it will fall to powder before our eyes, and with the evolution of considerable heat, thus showing that a chemical operation has taken place, in which the water has become chemically combined with the lime; for, unless excess of water has been used this powder will be just as dry to our senses as the original quicklime. This combination of lime with water is called hydrated lime, and if we weigh the powder resulting from either air slaking or water slaking we will find it to be about one-third heavier than the original quicklime from which it was produced, this additional weight being due to chemically combined water.

ATOMIC WEIGHTS

Chemists have found that elementary substances, such as calcium, carbon, oxygen and hydrogen always combine with each other in certain fixed weights, or multiples of such weights, which are called atomic weights, or combining weights; and hydrogen, which is the gas which causes balloons to rise, and the lightest of known elements, is taken as the unit of weight. (The reason balloons rise is that hydrogen is lighter than air, not that hydrogen has no weight of itself; just as wood floats upon water because it is lighter than the water. If hydrogen be placed in a vacuum it will fall, instead of rising, just as wood falls in air)

Measured by hydrogen as unity, the other elements which enter into the composition of lime in its various forms have the following atomic weights:

Calcium (Ca)	40
Oxygen (O)	16
Carbon (C)	12
Hydrogen (H)	1

CHEMICAL SYMBOLS

In order to save space and time each element is given a symbol to designate it, these symbols being usually the first one or two letters of the name of the element, and the symbols of the elements under consideration are as given above in parentheses. In designating chemical compounds these symbols are so used as to show not only the elements contained but the proportion of each element in the compound: Thus water, which is a chemical combination of two combining weights of hydrogen with one combining weight of oxygen, has the symbol H_2O, which means that in 18 pounds of water 2 pounds are hydrogen and 16 pounds are oxygen; but 2 is approximately 11 percent of 18, and 16 is about 89 percent of 18, so we say that water is 11 percent hydrogen and 89 percent oxygen.

The symbol for lime is CaO, meaning that 40 pounds of calcium are combined with 16 pounds of oxygen in every total of 56 pounds; or 71 percent of calcium and 29 percent of oxyge

The symbol for carbon di-oxide is CO_2, meaning that one combining weight of carbon is united with two combining weights of oxygen, or 12 parts by weight of carbon with 32 parts by weight of oxygen, so that this gas is a little more than 27 percent carbon and a little less than 73 percent oxygen.

In carbonate of lime we have three elements to consider: calcium, carbon and oxygen, and the symbol of this compound is CaO, CO_2 or $CaCO_3$, so that in a given weight of pure limestone we would have for every 40 pounds of calcium 12 pounds of carbon and 48 pounds of oxygen. The sum of these weights is just 100, so that 100 pounds of carbonate of lime contains 40 percent calcium, 12 percent carbon and 48 percent oxygen.

Hydrated lime has the symbol CaO, H_2O or CaH_2O_2, so that in a given weight of hydrated lime the elements would have the ratio 40:2:32, or 54 percent calcium, 2.7 percent hydrogen and 43.3 percent oxygen.

RELATIVE VALUE OF CALCIUM CARRIERS

Now let us see how much actual calcium we shall find in a ton of each of the different carriers mentioned:

Carrier	Symbol	Percentage composition				Pounds Calcium in one ton
		Ca.	O.	C.	H.	
Quicklime	CaO	71	29	..	...	1,420
Hydrated lime	CaO, H_2O	54	43.4	..	2.7	1,080
Carbonate of lime	CaO, CO_2	40	48	12	...	800

One ton of quicklime carries 1,420 pounds of calcium. To carry this quantity of calcium in hydrated lime would require as many hundred pounds of hydrated lime as 54, the quantity of calcium contained in 100 pounds of hydrated lime, is contained in 1,420 which is 26.3. It will therefore take 2,630 pounds of hydrated lime to carry as much calcium as is found in 2,000 pounds of quicklime. In the same way it is shown that 3,550 pounds, or nearly 2 tons, of carbonate of lime will be required to carry the calcium found in one ton of quicklime.

THE CARBONATES OF LIME

Three forms of carbonate of lime are on the market: one produced by grinding raw limestone, one found in the beds of marl sometimes found under muck beds, and one resulting from manufacturing processes in which the carbonate is produced by chemical processes analogous to that which is witnessed when we breathe through a tube into a glass of limewater. This process, by which the carbonate of lime is precipitated, to use the chemist's term, results in much finer powder than can be produced by ordinary grinding, and hence a precipitated carbonate of lime may be more quickly available than ground limestone. In actual practice, however, the experiments made by the Ohio Experiment Station have shown no practical superiority of one form of lime over the other, provided the limestone has been so ground that 80 percent of it will pass through a sieve having 100 meshes to the linear inch, and provided also, of course, that the two materials are used on the basis of the actual calcium contained. As the outcome of these experiments the Experiment Station is using either one ton of quicklime or two tons of ground limestone per acre, which ever can be spread on the field in these quantities for the least money.

To illustrate this point, let us suppose that ground limestone and quicklime are offered at the same point of shipment at $1.25 per ton for the former and $5.00 for the latter. Let us assume that the freight will be $1.50 per ton, and the cost of hauling from the car and spreading $1.00 per ton. Our account will then stand as follows:

	Quicklime *1 ton*	*Ground stone* *2 tons*
Cost at point of shipment	$5.00	$2.50
Freight	1.50	3.00
Hauling and spreading	1.00	2.00
Total	$7.50	$7.50

ADULTERATED LIMES

A factor which is not taken into the above account is the greater discomfort in handling quicklime than the ground stone. Moreover, sometimes, the so-called "agricultural lime" is suspected to contain more or less unburnt stone, ashes, etc., accumulating at the bottom of the kiln, which are ground up together. Such lime, of course, would not be pure quicklime, and very little adulteration of this sort would bring the value of the one ton of "agricultural lime" much below that of the two tons of limestone. On the other hand, the ground stone is not always so finely ground as it ought to be to produce the best results, and it may sometimes be ground from rock containing sand or earth, although this probably is seldom the case, for when a product is worth only about a dollar per ton there is less inducement to adulterate it than when the price is higher.

MAGNESIA

Magnesia (MgO) is the oxide of the element magnesium, which is very similar in its characteristics to calcium, and the two are generally found associated in ordinary limestones. Magnesium has a somewhat greater effect than calcium in correcting acidity, 84 pounds of magnesium carbonate being equivalent in this respect to 100 pounds of calcium carbonate. Within certain limits the presence of magnesium in the limestone, therefore, is an advantage; but when used in excess magnesium may cause injury rather than benefit—which is also true of calcium, or any other good thing. The difference between magnesium and calcium in this respect is that it requires a smaller amount of the former than of the latter to cause injury. Such injury is more liable to follow the use of magnesium lime, carrying magnesia in the caustic form, than when the carrier is in the carbonate form.

When the limestone carries nearly as much magnesium as calcium it is called a dolomite, and the use of quicklime made from such a stone might be questionable; when, however, the magnesia does not reach more than 25 to 30 percent in the lime there is but little danger of injury from it on ordinary Ohio soils, if applied at the usual rate of about a ton to the acre once in 4 or 5 years. There is but little danger from magnesia in the carbonate form.

THE CHIEF THING TO REMEMBER ABOUT LIME

The chief thing to remember about lime is that it is the natural calcium and magnesium carbonate which we find in limestone that does the work we want done in the soil, whether in feeding the plant or in neutralizing soil acidity, and that whatever be the carrier we may use, whether quicklime or hydrated lime, it will be quickly changed to the carbonate by the moisture and carbon di-oxide of the soil, and that the only reasons for using any other carrier than the natural carbonates are to secure the greatest fineness of division and to save freight and labor in handling.

WHEN TO USE LIME

Half the soils of Ohio—covering the region west of a line drawn from Sandusky through Columbus to the west line of Scioto county, excepting Williams and Fulton counties and adjoining portions of Henry and Defiance counties—lie over limestones. In this region there may be old fields in which the supply of lime in the plowed surface has become deficient, but as a rule the expense of a general application of lime should not be incurred until a preliminary test has been made. Such a test is best made by liming a narrow strip across a field and observing the effect on the clover crop. For such an experiment common hydrated or builder's lime may be used at the rate of 15 to 20 pounds per square rod or 2,000 to 3,000 pounds per acre

At the Experiment Station the best results have followed when the lime has been applied to the surface while the land was being prepared for corn, the cultivation of the corn crop and the subsequent plowings mixing the lime through the seed bed so thoroughly that when the clover crop has come along in its regular place in the rotation it has found the soil acidity thoroughly corrected.

THE LITMUS TEST

The litmus test is a simple chemical test for soil acidity, made by inserting a strip of blue litmus paper in moist soil and letting it stand for a few minutes. If the soil is acid, the paper will turn distinctly red. As the paper may sometimes be reddened by temporary conditions of acidity the actual application of lime as above described is much the better test. Litmus paper may be procured at most any drug store.

When lime is needed it should be applied in sufficient quantity to accomplish its work. At the Experiment Station the rule is to apply one ton of quicklime, 1⅓ ton of hydrated lime, or two tons of carbonate of lime per acre as a first application, this to be followed every four or five years thereafter—or every time the corn crop comes around in rotation—by half the above quantities.

Lime cannot be satisfactorily applied with the ordinary fertilizer drill, as it does not sow enough and will not feed slaked lime regularly. Several good lime spreaders are now on the market.

While, as above stated, the need for lime is doubtful over the western half of the state, the case is very different over a large part of eastern Ohio, where the rock floor is made up of shales and sandstones. At the Experiment Station lime is adding six to eight bushels of corn to the acre, two or three bushels each of oats and wheat, and is more than doubling the clover crop.

The Ohio Agricultural Commission has been authorized by law to extend to the trade in agricultural lime the same control now exercised over that in fertilizing materials.

WHAT CROPS TO LIME

In the experiments reported in this bulletin the lime has been applied to corn, in a 5-year rotation of corn, oats, wheat and clover, the lime being spread on the surface and harrowed in after plowing the land, and the outcome seems to have abundantly justified this practice. Many farmers, however, prefer to apply the lime when preparing for wheat, because the rush of work is not so great at that season and because the roads are usually in better condition then for hauling the lime.

Reference to the preceding tables will show that if we should take the average gain for lime on the land receiving the complete fertilizer carrying 30 pounds of nitrogen—Plots 17, 21, 23 and 24—and were to value corn with its stover at half a dollar per bushel, oats with its straw at one-third of a dollar, wheat with its straw at 90 cents and hay at $8.00 per ton, we would have the following as the value of the increase in the different crops due to the liming:

	Increase	Value
Corn, bus	10.25	$5.12
Oats, bus	1.70	0.57
Wheat, bus	3.53	3.18
Clover hay, tons	0.66	5.28
Timothy hay, tons	0.735	5.88
Total		$20.03

On these valuations the greatest gain from the liming has been found in the timothy crop, while the clover and corn have shown a nearly equal gain.

Attention has been called to facts which seem to indicate that a large part of the increase following lime should be ascribed to its action in favoring nitrification, but if it is to serve this purpose effectively it must be incorporated with that stratum of soil in which the nitrifying organisms perform this service and which is the same stratum in which the roots of corn and other crops find their sustenance; for the nitrifying organisms are living plants, whose existence depends upon the same conditions of moisture and air circulation required by corn roots. It the corn roots are exposed to free circulation of air they quickly perish; but they also perish if deprived of air for any length of time, as by being covered with water. Moisture is essential to their life, but an excess of water is fatal, because it excludes the air.

In one respect the corn roots have the advantage of the nitrifying bacteria; they may travel considerable distances in search of food, being connected at all times with s base of supplies in the stalk, from which they are pushed forward, but the bacteria have no such support, each minute organism being independent of all others and dependent solely upon the means of subsistence with which it finds itself in contact.

If, therefore, lime is to perform its full function in the soil it must be distributed throughout that layer of the soil which contains the necessary conditions of moisture and air circulation for the growth of crop roots, and must be so distributed that a particle of lime may be found in contact with every particle of soil.

When the lime is reduced to a fine powder, as by burning and slaking, or by grinding, and is then stirred into the surface of a plowed field the first steps have taken for its most effective service. The further stirrings which take place in the cultivation of the corn crop and in the plowings for the oats and wheat crops produce a still more intimate admixture of the particles of lime and soil, so that by the time the clover seeds are sown the conditions are as favorable as we can make them.

To delay the liming until the land is being prepared for wheat means a much less perfect mixture of lime and soil than results from liming the corn crop, and consequently a less perfect utilization of the lime by the clover, although it is much better to lime the wheat crop than not to lime at all.

It is sometimes asked whether the final outcome will not be the same, after a system of liming is established, whether the lime is put on the wheat or corn. The reply is that the necessity for repeating a dressing of a ton per acre of lime or limestone every four or five years means that much of the lime is lost, whether by being dissolved and carried into the drainage waters, or by being fixed in unavailable form; for the consumption of lime as plant food is comparatively insignificant, as shown by the table below, giving the calculated amounts of lime carried off the land by the average crops grown on the limed ends of Plots 17, 21, 23 and 24 in the experiments above described:

Crop	Average yield per acre		Pounds of lime (CaO)	
	Grain bus.	Stover, straw or hay lbs.	In grain	In stover, straw or hay
Corn	57.18	2.658	0.96	14.24
Oats	49.73	2.574	1.75	12.87
Wheat	27.82	2.876	0.83	7.76
Clover	.....	3.815	....	76.30
Timothy	.....	4.514	....	14.40

A total of 129 pounds of lime, equivalent to less than 250 pounds of limestone. Experiments have shown, however, that we never recover in the increase of crop more than 60 to 80 percent of the phosphorus or potassium given in fertilizers or manure, and the same principle no doubt applies to the recovery of lime, so that it is probable that an annual application of 80 to 100 pounds of limestone would be required to replace that taken off by such crops as those grown in these experiments. But experience has shown that the chief purpose of liming the land is not to supply lime as plant food, but to promote nitrification and to correct soil acidity, and for these purposes the lime must be used in much larger quantity than would be required were its function limited to the direct feeding of the plant.

In performing these functions the lime enters into combination with the soil acids, forming neutral salts, some of which are soluble and are carried into the drainage waters. In the case of the cereal crops the chief function of lime is apparently to favor the action of the nitrifying bacteria, through whose agency the nitrogen held in the remains of previous vegetation is made available, probably in the form of nitrate of lime. Thus we see that Plot 8, which receives phosphorus and potassium, but no nitrogen, produces less grain on the unlimed land than any of the plots which receive the same quantity of phosphorus and potassium with nitrogen in addition. When lime is added, however, Plot 8 produces more corn than any of the plots which receive nitrogen but no lime, although on the limed land the addition of nitrogen to phosphorus and potassium causes a further increase in yield. In the oats crop the effect of lime is too small to justify definite conclusions. In the wheat crop the increase from lime is smaller than that from nitrate of soda, but greater than that from other carriers of nitrogen, thus indicating that much of the effect of lime is due to the making available of organic and ammonia nitrogen.

In the clover crop nitrogen produces no increase on the unlimed land when given in other carriers than nitrate of soda, and the increase from this salt is apparently due to the sodium, rather than to the nitrogen contained.

These facts seem to justify the conclusion that the lime applied to the corn crop in liberal quantity has encouraged the production of nitrates for several succeeding crops, and has furnished a sufficient quantity of alkaline base to neutralize any excess of nitric acid produced, beyond the capacity of the crops to utilize it, and thus has prepared a neutral soil in which the clover has found the conditions essential to its full development.

The increase in the timothy crop may be accounted for in part in the advantage gained by its association with clover, but the darker color of the timothy growing on limed land is evidence that it is having access to a larger supply of nitrogen than is found in the unlimed land, thus again suggesting that much of the effect of lime is due to its forwarding of nitrification.

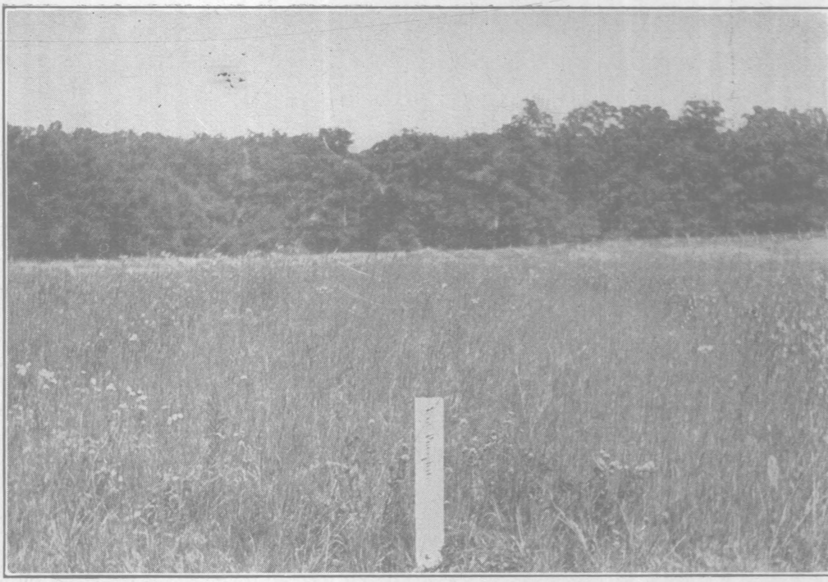
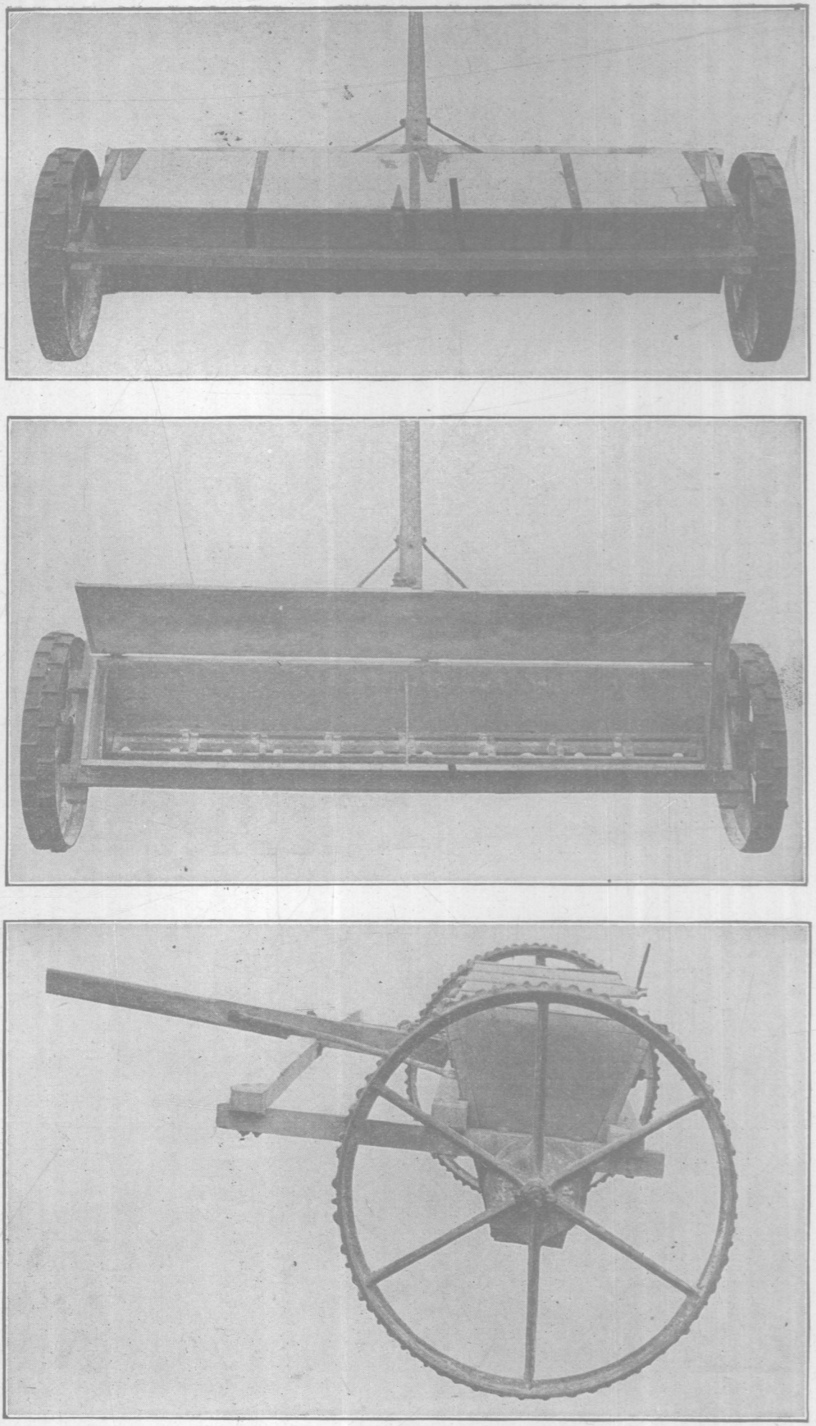


Fig. 3. Unlimed end of Plot 2, Section E, June 1902.
The growth is timothy, with only an occasional clover plant.

Fig. 4. Limed end of Plot 2, Section E., June 1902.
A fair crop of clover, with considerable "White-top."



LIME SPREADER.

TO MAKE A LIME SPREADER

Make a hopper similar to that of an ordinary grain drill, except that it should be 8 feet long with sides and top 18 to 24 inches wide. Let the bottom be 5 inches wide in the clear and cut in it a row of oval holes, one inch wide, two inches long and 8 inches apart. Make a false bottom with holes in it of the same size and shape as those of the main bottom, and so spaced that they will register. Let this false bottom slide loosely under the hopper, moving upon supports made by leaving a space for it above bands of strap iron, which should be carried around the hopper every two feet to strengthen it. Both bottom pieces should be of smooth, seasoned hardwood, 7/8 inch thick and well oiled or painted. To the lower strip rivet a V-shaped arm, extending an inch in front of the hopper, with a half inch hole in the point of the V, in which drop the end of a strong lever, bolting the lever loosely but securely to the side of the hopper, 3 or 4 inches above the bottom. Let the lever extend 6 or 8 inches above the top of the hopper, and fasten to the side of the hopper a guide of strap iron, in which the lever may move freely back and forth. The object of this lever is to regulate the size of the openings by moving the bottom plate. Make a frame for the hopper, with a tongue to it, similar to the frame of an ordinary grain drill.

Get a pair of old mowing machine wheels, with ratchets in the hubs, and two pieces of round axle of sufficient length to pass through the wheels and frame and into the ends of the hopper, where they are welded to a bar of iron 1¼ inch in diameter and the length of the inside of the hopper. The axles should be fitted with journals, bolted to the underside of the frame.

Make a reel to work inside of the hopper by securing 8 short arms of ¼ inch by ¾ inch iron to the axle, and fastening to these 4 beaters or wings of ⅜ inch by ⅝ inch iron, and about an inch shorter than the inside of the hopper, the reel being so adjusted that the wings will almost scrape the bottom of the hopper but will revolve freely between the sides. These arms should be made of two pieces, bent so as to fit around the axle on opposite sides, and secured by small bolts passing through the ends and through the beater which is held between them. The diameter of the completed reel is about 5 inches and its length an inch or so less than that of the inside of the hopper. This reel serves as a force feed.

Tack two pieces of oilcloth to the bottom of the hopper, one in front and one behind, of sufficient width to reach the ground. These are to reduce the annoyance to man and team of the flying lime dust.